GULFMET Bilateral comparison GULFMET.PR-K4.2021.1 between TÜBITAK UME and SASO NMCC for

Luminous Flux.

Final Report

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ABSTRACT

This report describes the Bilateral Comparison GULFMET.PR-K4.2021.1 between TÜBİTAK UME and SASO NMCC for Luminous Flux, conducted by the Regional Metrology Organization "the Gulf Association for Metrology" (GULFMET). The comparison was, in fact, a combination of two bilateral comparisons with the same link/pilot laboratory – TÜBITAK Ulusal Metroloji Enstitüsü (TÜBITAK UME), Türkiye. The non-link laboratories were the National Measurement and Calibration Center at Saudi Standards, Metrology and Quality Organization (SASO NMCC), The Kingdom of Saudi Arabia, and the National Institute of Standards (NIS), Egypt. The comparison was registered as GULFMET.PR-K4.2021, and based on CCPR WG-KC feedback to avoid confusion, two separate reports have been prepared. Accordingly, a separate report has been prepared regarding the comparison of luminous flux between TÜBİTAK UME and NIS (GULFMET.PR-K4.2021.2).

The aim of the comparison was to link the SASO NMCC measurement result to the CIPM key comparison CCPR-K4, conducted by the Consultative Committee for Photometry and Radiometry (CCPR).

Three Polaron LF200W type of the lamps, produced as the transfer standard for luminous flux measurements and belonging to the pilot laboratory, were used as artefacts. The sequence of measurements was pilot – participant – pilot.

The analysis of the comparison was performed following the approach described in the Appendix A of the Guidelines for CCPR and RMO Bilateral Key Comparisons (CCPR-G5).

CONTENTS

1 Introduction

This report describes the bilateral comparison (GULFMET.PR-K4) on luminous flux between The Scientific and Technological Research Council of Turkey – National Metrology Institute (TÜBITAK UME) and National Institute of Standards (NIS) in the frame of the Project of Development and Realization Measurement and Calibration System as a GULFMET bilateral comparison. This key comparison was carried out under the auspices of the Gulf Association for Metrology (GULFMET), which is the Regional Metrology Organization (RMO) established under the auspices of GCC Standardization Organization (GSO). According to paragraphs T.8 and T.9 of the MRA, a bilateral key comparison was carried out between two institutes as outlined in CIPM Guideline for key comparisons [1]. The scheme for performing comparisons within the framework of EURAMET is presented in Euramet Guidelines on Conducting Comparisons [2]. RMO key comparisons in the field of photometry and radiometry are performed in accordance with the Guidelines for CCPR and RMO Bilateral Key Comparisons (CCPR-G5) [3] and Guidelines for RMO PR Key Comparisons (CCPR-G6) [4].

In 1997, the Comite International des Poids et Mesures (CIPM) had initialized two key comparisons CCPR-K3a of luminous intensity and CCPR-K4 of luminous flux with the Physikalisch-Technische Bundesanstalt (PTB), Germany, acting as pilot laboratory. The maintained units of 16 national metrological laboratories and of the Bureau International des Poids et Mesures (BIPM) were compared in a 'star-type' structure, using more than 200 lamps as transfer standards. The results of these comparisons are key comparison reference values (KCRV) for the two quantities. All results were published1 in 1999 and the DOEs are listed in the data base [5] of the BIPM.

In 2010, under the auspices of the European Association of National Metrology Institutes (EURAMET) as the RMO two international key comparisons on luminous intensity (EURAMET.PR-K3.a) and luminous flux (EURAMET.PR-K4) were carried out [6]. The units are transferred by batches of incandescent lamps from the participants to the pilot laboratory, the PTB. When it was decided to carry out the EURAMET Key Comparison, the Institute National de Métrologie (BNM-INM / CNAM, France) and the Instituto Nazionale di Ricerca Metrologica (INRIM, Italy) agreed to act as link laboratories for both units. Key comparisons are intended to determine the Degrees of Equivalence (DoE) for each non-link participant and the associated expanded uncertainty. The DoE for a quantity states for a participant the relative difference of his value with the related Key Comparison Reference Value (KCRV).

In 2015, under the auspices of EURAMET as RMO, one bilateral key comparison on luminous flux (EURAMET.PR-K4.3) was organised. The participants for this bilateral comparison were IO-CSIC and TÜBITAK UME. IO-CSIC was a link laboratory (IO-CSIC participated in CCPR-K4) and TÜBITAK UME is linked to the CCPR-K4 KCRV [7].

On the bases of the referenced documents, the luminous flux comparison between TÜBITAK UME and SASO NMCC was carried out within the scope of GULFMET.PR-K4, whose technical protocol was approved by WG-KC of CCPR in November 2021 [8]. TÜBITAK UME (Türkiye) acts as pilot and linking laboratory for this comparison (TÜBITAK UME is connected to CCPR-K4 through EURAMET.PR-K4.3 comparison [7]). TÜBITAK UME is responsible for developing the comparison protocol, registering the comparison, for Pre-Draft A and subsequent work. This bilateral comparison is intended to determine the Degree of Equivalence (DoE) for the participant (SASO NMCC (Saudi Arabia)) and its associated expanded uncertainty. The DoE sets the relative difference of the participant (SASO NMCC (Saudi Arabia)) measurement results to the KCRV, which was determined in the CCPR-K4 key comparison. Since CCPR-K4, KCRV are maintained by the participants of CCPR-K4. TÜBITAK UME transfers its maintained values by a set of lamps to SASO NMCC.

A third party (CCPR-WG-KC Secretary) was designated for the comparison, and all the measurement results (from the non-link laboratory (SASO NMCC (Saudi Arabia)) and the linking laboratory (TÜBITAK UME)) were submitted to the third party upon completion of each measurement cycle, to ensure blindness of the comparison. At completion of all measurements, the third party sent all the data received to the linking laboratory.

This document reports the final results of the bilateral comparison of luminous flux between TÜBITAK UME and SASO NMCC, and comparison with the KCRV and the DoE for the non-link laboratory. All main information, the data collection and the evaluation are given in the following sections, and are supplemented with more details in the Appendix.

2 GENERAL INFORMATION

2.1 List of Participants

The acronyms of the participating are listed in the first column of Table 1. The names of the institute and the contact person with the e-mail address are given in the second column. The third column shows the country and the city of each participant. In the last column, role of each laboratory is entered.

Table 1. List of participant and contact information

Acronym	**Institute name** ***Contact person / Email***	**Country** ***City***	**Role**
TÜBITAK UME	TÜBITAK Ulusal Metroloji Enstitüsü Ferhat Sametoglu, Email : ferhat.sametoglu@tubitak.gov.tr	Türkiye *Kocaeli*	Pilot
SASO NMCC	National Measurement and Calibration Center - Saudi Standards, Metrology and Quality Organization Mohammed D. Almelfi, Email : m.melfi@saso.gov.sa	Saudi Arabia Riyadh	Participant

2.2 Time Schedule

Preparation of full protocol agreed by participants was finished in October 2021 and protocol and notification of the comparison were sent to GULFMET TC-PR Chairman in October 2021. In November 2021, the protocol was approved by CCPR-WG-KC and registered at KCDB. According to the protocol, the comparison was carried out in the form of a star comparison. After that, the first measurements of three luminous flux lamp standards were performed at TÜBITAK UME between February 2022 and April 2022 and then information about the measurement results with expanded uncertainties were sent to the third party (Joële Viallon, jviallon@bipm.org) via email (29 April 2022). After that the lamps were sent to SASO NMCC. Measurements at SASO NMCC were performed in October 2022 and information about the measurement results with expanded uncertainties were sent to the third party (Joële Viallon, jviallon@bipm.org) via email. Subsequently, the lamps were returned to TÜBITAK UME, in where the second measurements were performed in December 2022 and obtained results were sent to third party (Joële Viallon, jviallon@bipm.org) via email (16 December 2022). After collection of all the results, the third party sent all the data to the pilot laboratory (TÜBITAK UME), which implemented Pre-Draft A procedures.

When the Pre-Draft A procedures were completed in October 2023, TÜBITAK UME prepared the Draft A report following the CCPR Guideline G5 "Guidelines for CCPR and RMO Bilateral Key Comparisons". Subsequently, Draft B report following the CCPR Guideline G5 "Guidelines for CCPR and RMO Bilateral Key Comparisons" was prepared and sent for approval in November 2023. Draft B report was revised and resubmitted for review in light of the CCPR-WG-KC feedback received in September 2024. All comments have been considered and the report is deemed approved.

2.3 Comparison Artefact (Transfer Standard)

In the comparison, three Polaron LF200W type of the lamps produced as the transfer standard for luminous flux measurements were used (serial numbers: 352, 353 and 355). A picture of one of the lamps is shown in Figure 1.

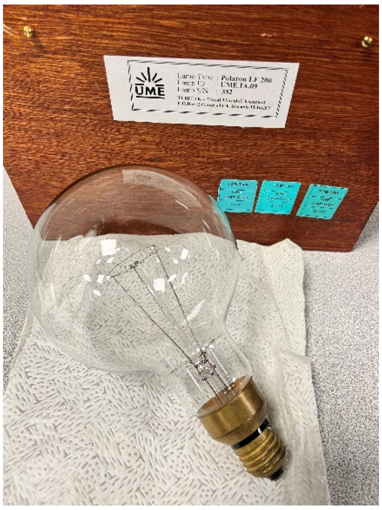

Figure 1. Image of transfer standard lamp (Polaron LF200W) used for GULFMET.PR-K4.2021.

The measurement artefacts were provided by the pilot laboratory (TÜBITAK UME) and were hand-carried by expert personnel for the comparison measurements. Additional information of the LF200W lamps is given below:

- Lamp base: E27 Edison screw base.
- Nominal luminous flux: 1900 lm.
- Rated operating current: around 2 A. Rated operating voltage: around 90 V.
- Typical value of CCT (or distribution temperature): 2740 K.

2.4 Measurement Conditions

The measured quantity was the luminous flux of a lamp. This photometric quantity was measured for the defined operating conditions of each lamp, where the operating current acted as the setting parameter. The lamps were powered by a DC power supply with the polarity as it was defined at TÜBITAK UME. The exact values of the lamps operating current and voltage were measured and reported by the participants. The measurements were carried out under appropriate laboratory conditions with the room temperature staying between 19 ºC and 25 ºC. The operating DC current, the lamp voltage and the color temperature were recorded and reported together with the measured luminous flux values. The luminous flux of the lamps was measured independently three times. Each independent measurement was carried out for the lamp being realigned in the measurement facility and being switched off and on after a break of 2 h for each lamp. In all laboratories, all lamps were measured using an integrating sphere based measurement system. The lamps were vertically installed in the center of the sphere, the lamp cap pointing upwards. The photometer/spectrometer used with the sphere did not receive direct radiation from the lamp. The lamps were aligned following the usual laboratory procedures. Before installing in the facility, the lamps were inspected for damage or contamination of the lamp bulb or cap. No damage or contamination was recorded during the comparison.

No drift of the traveling lamps was noticed during the period of the comparison. Therefore no drift correction and corresponding uncertainty were applied.

3 Measurements performed at SASO-NMCC

For the comparison measurements, two SASO-NMCC standard luminous flux lamps were used as references for Luminous Flux measurements. Both of them are (Osram WI 40/G). Refer to the following table for the details of the used equipment in the setup during the comparison's measurements. The schematic of the 2 m Integrating sphere and its component equipment is shown in Figure 2.

Instrument used:

#	**Instrument**	**Manufacturer - Model**
1	Lamp (Ref & DUT)	Ref: Osram WI 40/G DUT: Artifacts (Polaron LF200W)
2	Auxiliary Lamp	Labsphere SCL-1400
3	Spectrometer	Labsphere, CDS-610
4	Precision Current Source	Keithley, 6220
5	Digital Multimeter (through lamp)	Keysight, 3458A
6	Digital Multimeter (through Shunt)	Keysight, 3458A
7	Shunt Resistance	Guildline Instruments, 9230A-15R
8	DC Power Supply	Heinzinger, PTN 250-20
9	PC Computer	--
10	Temperature Probe	Omega, Type J, TC08
11	White Baffles	--
12	Fiber Optic Cable	--

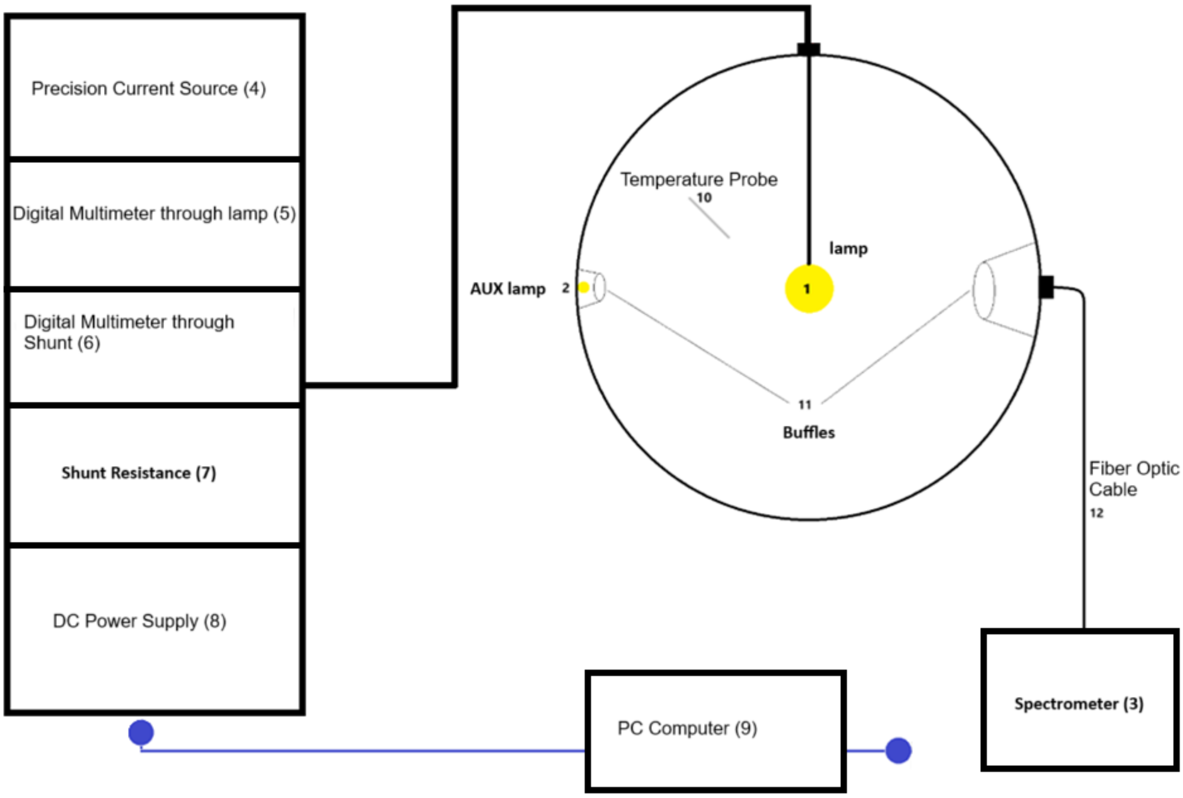

Figure 2. Luminous Flux Measurement System of SASO-NMCC.

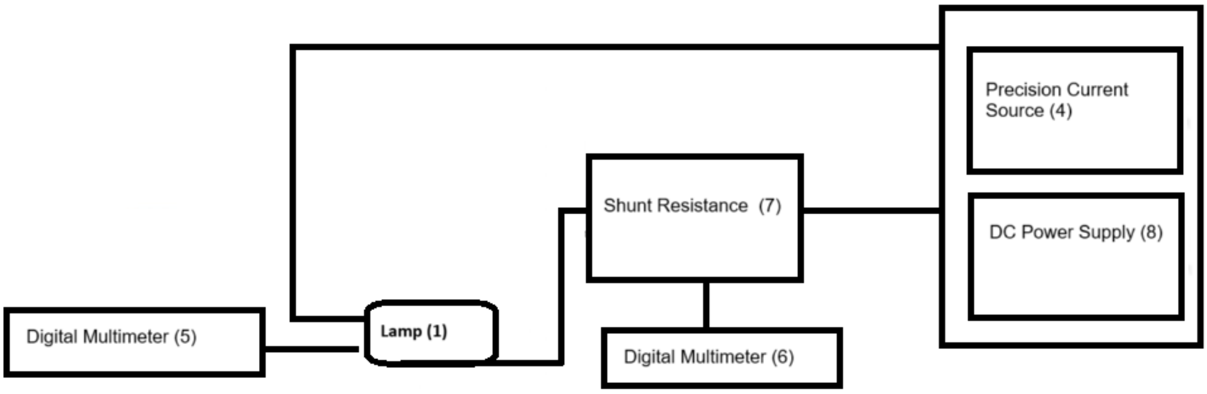

Figure 3. Electrical connection of the System of SASO-NMCC.

3.1 Measurement Conditions

Total Luminous Flux in the unit Lumen was measured for the artifact lamps according to SASO-NMCC calibration procedures. The measurements were done with adhering the electrical polarity of the DC current which was defined by the pilot laboratory. All lamps were operated using the four-pole technique. Electrical current and voltage were monitored and recorded during every measurement. Every measurement was carried in appropriate ambient temperature (from 19 ºC to 23 ºC). Two SASO-NMCC standard luminous flux lamps were used as reference lamp for these measurements. Every lamp operated during the comparison was warmed up for fifteen minutes and kept untouched after the measurement for another fifteen minutes to cool down. Each lamp was measured in the center of the integrating sphere with presence of optical baffles to prevent the spectrometer of any direct light from the source. An auxiliary lamp was used from the side of the sphere to eliminate the geometrical differences between the reference lamps and the lamps under test. The Correlated Color Temperature (CCT) was measured for each lamp on SASO-NMCC photometric bench.

3.2 Geometric Conditions

The luminous flux was measured in the relative method, comparing the artifacts to the SASO-NMCC luminous flux standard lamps in a 2 m in diameter integrating sphere.

The measurements were done under following conditions:

- Both lamps (Ref & DUT) were mounted in the center of the sphere vertically and cap up,
- Auxiliary lamp is mounted at the side of the sphere,
- Optical baffles mounted in places which prevent the direct light from the lamps and the auxiliary lamp.

3.3 Electrical Conditions

The lamps used during the measurements were operated by the electrical devices in the previous table. The devices were controlled by a LabVIEW software to maintain the stability of the electrical current. To protect the tungsten filament of each lamp the electrical current was ramped up and down for over three minutes, avoiding electrical shocks to the filament.

3.4 Thermodynamic Conditions

The ambient temperature of the laboratory was within the range of 19 ºC and 23 ºC, and the humidity was in the range 35% rh and 55% rh. The Temperature inside the integrated sphere was monitored by the temperature probe listed in the used instrument.

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3.5 Temporal Conditions

The electrical current was ramped up and down for over three minutes, avoiding electrical shocks to the filament. Each lamp was given a break for at least two hours after the measurement before it can be operated again.

3.6 Determination of the Luminous Flux

Total Luminous Flux in the unit Lumen was measured for the artifact lamps according to SASO-NMCC calibration procedures. The SASO-NMCC standard lamps were calibrated to perform the relative method of determining the luminous flux quantity through the following model function:

$$\boldsymbol{\Phi_c = (\Phi_r - \delta\Phi_r).\left(\frac{y_c}{y_r}\right).\left(\frac{y_{ar}}{y_{ac}}\right).\left(\frac{J_{rm}}{J_{rs}}\right)^{-mi}.\left(\frac{J_{cm}}{J_{cs}}\right)^{mi}.(1 - Pnl - Pt)}$$

Where:

Φ_c : Luminous flux of DUT lamp

Φ_r : Luminous flux of reference lamp

$\delta\Phi_r$: Drift of reference lamp

y_r : Reference measured signal

y_c : DUT measured signal

y_{ar} : Aux signal measured for Reference

y_{ac} : Aux signal measured for DUT

J_{rm} : Measured REF lamp current

J_{rs} : Nominal REF lamp current

J_{cm} : Measured DUT lamp current

J_{cs} : Nominal DUT lamp current

m_i : Mismatch index of lamp current

P_{nl}: Non-linearity of sphere detector

P_t : Temperature effect of sphere photometer

3.7. Reporting of the Results

Luminous Flux Results performed at SASO-NMCC:

Values obtained by SASO-NMCC for luminous flux of the comparison transfer standard lamps are presented in Table 2 (more details are given in the Appendix section).

Table 2. Comparison measurement results of SASO-NMCC within the scope of GULFMET.PR-K4.2021.

Lamp No.	Lamp current I / A	Luminous flux Φ / lm
352	1.9000	1927
353	1.9000	1864
355	1.9000	1886

3.8 Uncertainty of Measurements

Table 3 shows the uncertainty budget in measurements of luminous flux al SASO-NMCC.

Table 3. Uncertainty Budget of SASO-NMCC for the Determination of Luminous Flux

Source of uncertainty	Standard uncertainty (%)
Uncertainty of luminous flux of reference lamp, $\boldsymbol{\Phi}_{Ref}$	0.90
Uncertainty of drift of reference lamp, $\delta\boldsymbol{\Phi}_{Ref}$	0.10
Uncertainty of signal measured for DUT, y_c	0.0065
Uncertainty of signal measured for REF, y_{Ref}	0.0042
Uncertainty of aux signal measured for REF, $y_{A,Ref}$	0.019
Uncertainty of aux signal measured for DUT, $y_{A,c}$	0.019
Uncertainty of measured REF lamp current, J_{rm}	0.00020
Uncertainty of measured DUT lamp current, J_{cm}	0.0039
Uncertainty of mismatch index of lamp current, m_i	0.15
Uncertainty of non-linearity of sphere detector, P_{nl}	0.087

Uncertainty of temperature effect of sphere photometer P_t	0.087
Combined standard uncertainty (k = 1)	0.93
Combined expanded uncertainty (k = 2)	1.9

4 Measurements performed at TÜBITAK UME

For the bilateral comparison GULFMET.PR-K4, TÜBITAK UME used the same standard luminous flux facility that was used during EURAMET.PR-K4.3 [7]. The luminous flux measurements were carried out using a 2 m in diameter integrating sphere, by direct substitution with standard lamps. The integrating sphere is equipped with a V(λ)-corrected, cosine corrected photometer, a baffle screen, an auxiliary lamp and a temperature sensor. A baffle of 38 cm in diameter is set to a distance of about 1/3 of the distance from the detector to the sphere centre. The integrating sphere is also equipped with an auxiliary lamp (100 W/24V, tungsten) on the sphere wall. It is used to measure the self-absorption effects of a lamp in the sphere. A temperature sensor is mounted at the back side of the baffle, and the air temperature inside the sphere during measurements is monitored.

Since EURAMET.PR-K4.3 the KCRV has been maintained at TÜBITAK UME by means of a group of luminous flux standard lamps. The lamps were compared with each other at least once every two years. These measurements allowed to estimate an uncertainty $u_{TÜBITAK\ UME,st}$ associated with stability of TÜBITAK UME scale between EURAMET.PR-K4.3 and GULFMET.PR-K4:

$$u_{\text{TÜBITAK UME},t} = 0.46\%$$

At TÜBITAK UME, the lamps were calibrated by substitution method as comparison with two standard lamps. The three lamps are a part of a larger batch of lamps maintaining the luminous flux unit realized at TÜBITAK UME. The results of TÜBITAK UME measurements of luminous flux for the GULFMET.PR-K4 comparison lamps are presented in Table 4 (more details are given in the Appendix section).

Table 4. Comparison measurement results of TÜBITAK UME with SASO-NMCC within the scope of GULFMET.PR-K4.2021

Lamp No.	**Lamp current** I / A	**Luminous flux** Φ / lm	
		Before	**After**
352	1.9000	1914	1911
353	1.9000	1846	1845
355	1.9000	1881	1877

Total random uncertainty of TÜBITAK UME measurement during the GULFMET.PR-K4 comparison consists of the following components: reproducibility of the independent measurements, instability of lamp power supply and self-absorption correction. Same facility was used during EURAMET.PR-K4.3, then we assume that the random uncertainty was the same during both comparisons. Budget of the random uncertainty is presented in Table 5.

The measurements at TÜBITAK UME were carried out at room temperature of (23.0 ± 1.0) °C and humidity of (45.0 ± 10.0) %rh.

Table 5. Budget of random uncertainty (uncorrelated effects) of TÜBITAK UME measurements during EURAMET.PR-K4.3 and GULFMET.PR-K4.

Source of uncertainty	Relative standard uncertainty of luminous flux, %
Repeatability of independent measurements	0.030
Power supply instability	0.030
Self-absorption correction	0.020
Total random uncertainty $U_{TÜBITAK\ UME,\ r}$	**0.047**

5 LINK TO THE CCPR KCRV

5.1 Summary of Measurement Results

The luminous flux values measured between TÜBITAK UME and SASO NMCC are summarized in Table 6.

Table 6. The results of the measurements for all three lamps by TÜBITAK UME and SASO NMCC

Lamp serial number	**Current I / A**	**Luminous flux / lm**		
		SASO NMCC $\Phi_{SASO\ NMCC,i}$	**TÜBITAK UME before** $\Phi_{TÜBITAK\ UME,i}$	**TÜBITAK UME after** $\Phi_{TÜBITAK\ UME,i}$
352	1.9000	1927	1914	1911
353	1.9000	1864	1846	1845
355	1.9000	1886	1881	1877

Compared to the other lamps, the slight difference in the measurement result of lamp number 353 is thought to be due to instability in the system during the measurements carried out by SASO-NMCC.

5.2 Degree of Equivalence of SASO NMCC

Unilateral Degree of Equivalence (DoE) was evaluated in accordance with the Equation (2) of the “Guide for CCPR and RMO Bilateral Key Comparisons (CCPR-G5) [3]

$$D_{SASO\ NMCC} = D_{TÜBITAK\ UME} + {y_{SASO\ NMCC}}/{y_{TÜBITAK\ UME}} - 1$$

Where

- $D_{SASO\ NMCC}$ is the unilateral DoE for SASO NMCC
- $D_{TÜBITAK\ UME}$ = 0.65% is the unilateral DoE for TÜBITAK UME, calculated during the EURAMET.PR-K4.3 [7]

- $^{y_{SASO\ NMCC}}/_{y_{TÜBITAK\ UME}} - 1 = \bar{\Delta}$ is the average value of the ratio between the SASO NMCC result and the TÜBITAK UME average result for the 3 lamps that have circulated in this comparison, subtracting unity to obtain DoE.

The mean values and the relative differences are presented in Table 7.

Table 7. Results of the comparison between SASO NMCC values and TÜBITAK UME values.

Lamp **Serial number**	**Current** ***I* / *A***	**Luminous flux / lm**		**Relative difference**
		SASO NMCC $\Phi_{SASO\ NMCC}$	**TÜBITAK UME** $\Phi_{TÜBITAK\ UME,i}$	
352	1.9000	1927	1913	0.00752
353	1.9000	1864	1845	0.01006
355	1.9000	1886	1879	0.00369
			Mean difference $\bar{\Delta}$ =	**0.00709**

then

$$D_{SASO\ NMCC} = 0.65\% + 0.71\% = 1.36\%$$

5.3 Uncertainty of DoE

The uncertainty on the unilateral degree of equivalence of a participant non-link laboratory is calculated according to the following equation

$$u^2(D_{\text{non-link lab}}) = u^2_{\text{non-link lab}} + \underbrace{u^2(x_{\text{ref}})}_{\text{CCPR-K4}} + \underbrace{u^2_{\text{link}}}_{\text{linking quality}} + \underbrace{u^2_{BC}}_{\text{Bilateral Comparison}}$$

Where

1) $u_{\text{non-link lab}}$ is the total standard uncertainty of the non-link laboratory for a single artifact. This includes uncertainties due to both correlated and uncorrelated effects. According to uncertainty budgets given in the Section 3.8:

$$u_{\text{SASO NMCC}} = 0.93\%$$

2) $u(x_{\mathrm{ref}})$ is the relative standard uncertainty associated with the Key Comparison Reference Value ($u(x_{\mathrm{ref}})$ = 0.1% see KCDB on BIPM website).

3) The third contribution considers the quality of the link provided by the link laboratory

$$u_{link}^2 = u_{\text{TÜBITAK UME,st}}^2 + u_{\text{TÜBITAK UME,EURAMET.PR}-\text{K4.3}}^2 + u_{\text{TÜBITAK UME,BC}}^2$$

It includes

- The standard uncertainty associated with stability (reproducibility) of the link laboratory's scale between the EURAMET.PR-K4.3 and BC, $u_{\text{TÜBITAK UME,st}}$
- The standard uncertainty associated with uncorrelated effects (random uncertainty) of the link laboratory during the EURAMET.PR-K4.3, $u_{\text{TÜBITAK UME,EURAMET.PR}-\text{K4.3}}$
- The standard uncertainty associated with uncorrelated effects (random uncertainty) of the link laboratory during the BC, $u_{\text{TÜBITAK UME,BC}}$

These three components were analyzed in the Section 4 and estimated as 0.46%, 0.047% and 0.047% respectively.

4) The last contribution u_{BC} (in CCPR-G5 it's represented by the symbol s_{BC}) is the bilateral comparison effect. The only effect that we can consider as BC effect is instability of the artifact. We estimated the standard uncertainty associated with the lamp's instability as the maximum drift of all three lamps (Table 4). Therefore this value for SASO NMCC is given below:

$$u_{BC,SASO\ NMCC} = 0.21\ \%$$

Combining all estimated components, we can calculate the target uncertainties for the participant non-link laboratoriy:

$$u(D_{SASO\ NMCC}) = \sqrt{0.93^2 + 0.10^2 + 0.46^2 + 0.047^2 + 0.047^2 + 0.21^2} = 1.1\%$$

The expanded uncertainties of the non-link laboratory was obtained as follows:

$$U(D_{SASO\ NMCC}) = 2u(D_{SASO\ NMCC}) = 2.2\%$$

6 SUMMARY OF COMPARISON RESULTS

The determined degree of equivalences of the non-link laboratory (SASO NMCC) and its associated expanded uncertainty are summarized in Table 8.

Table 8. Degrees of equivalence (DoE) and associated expanded uncertainties of non-link laboratories participating in the luminous flux comparison (GULFMET.PR-K4.2021.1)

Non-link Laboratory	DoE $D_{non\text{-}link\ laboratory}$	Expanded uncertainty (k = 2) $U(D_{non\text{-}link\ laboratory})$
SASO NMCC	1.36%	2.2%

7 LITERATURE

[1] Guidelines for CIPM key comparisons, 1 March 1999

[2] Guide No.3, Euramet Guidelines on Conducting Comparisons Ver 02.7 (2002)

[3] Guidelines for CCPR «Guidelines for CCPR and RMO Bilateral Key Comparisons»(CCPR-G5, October 10th, 2014).

[4] Guidelines for RMO PR Key Comparisons (CCPR-G6 Version 1.0, 10 October 2014)

[5] CCPR-K4 report, http://kcdb.bipm.org/appendixB/appbresults/ccpr-k4/ccpr-k4.pdf.

[6] BIPM database: http://kcdb.bipm.org/appendixB/appbresults/EURAMET.PR-K3.a/EURAMET.PR-K3.a_Technical_Protocol.pdf

[7] A. Pons, J. Campos, F. Sametoglu. Bilateral comparison of luminous flux (EURAMET.PR-K4.3), Final Report, February 2019.

[8] https://www.bipm.org/kcdb/comparison?id=1789

8 Appendix

8.1 Detailed measurements results

8.1.1 Measurements results at TÜBITAK UME (round 1)

Lamp **S. No**	**Current** ***I* (A) ± *U*(A)**	**Voltage** ***U* (V) ± *U*(V)**	**Luminous Flux** ***Φ* (lm) ± *U*(lm)**	**Correlated Color Temperature** ***T* (K) ± *U*(K)**
352	1.90000 ± 0.00022	86.4891 ± 0.0022	1914 ± 33	2752 ± 25
			1917 ± 33	2752 ± 25
			1912 ± 33	2751 ± 25
		average	**1914 ± 33**	**2752 ± 25**
353	1.90000 ± 0.00021	86.0381 ± 0.0038	1844 ± 32	2730 ± 25
			1846 ± 32	2730 ± 25
			1848 ± 32	2730 ± 25
		average	**1846 ± 32**	**2730 ± 25**
355	1.90000 ± 0.00022	86.0382 ± 0.0012	1878 ± 33	2745 ± 25
			1883 ± 33	2744 ± 25
			1880 ± 33	2745 ± 25
		average	**1881 ± 33**	**2745 ± 25**

8.1.2Measurements results at SASO NMCC

Lamp S. No	Current *I* (A) ± *U*(A)	Voltage *U* (V) ± *U*(V)	Luminous Flux *Φ* (lm) ± *U*(lm)	Correlated Color Temperature *T* (K) ± *U*(K)
352	1.90000 ± 0.00030	86.6301 ±0.0019	1931 ± 18	2732 ± 8
			1930 ± 18	2733 ± 8
			1931 ± 18	2733 ± 8
			1927 ± 18	2733 ± 8
			1921 ± 18	2733 ± 8
			1919 ± 18	2733 ± 8
			1928 ± 18	2733 ± 8
		average	**1927 ± 18**	**2733 ± 8**
353	1.90000 ± 0.00024	86.1702 ±0.0021	1867 ± 17	2720 ± 8
			1869 ± 17	2719 ± 8
			1870 ± 17	2719 ± 8
			1861 ± 17	2719 ± 8
			1857 ± 17	2719 ± 8
			1858 ± 17	2719 ± 8
			1866 ± 17	2719 ± 8
		average	**1864 ± 17**	**2719 ± 8**
355	1.90001 ± 0.00074	87.9330 ±0.0011	1902 ± 19	2723 ± 8
			1902 ± 19	2723 ± 8
			1905 ± 19	2723 ± 8
			1893 ± 19	2723 ± 8
			1892 ± 19	2723 ± 8
			1891 ± 19	2723 ± 8
			1820 ± 19	2723 ± 8
		average	**1886 ± 19**	**2723 ± 8**

8.1.3Measurements results at TÜBITAK UME (round 2)

Lamp S. No	Current *I* (A) ± *U*(A)	Voltage *U* (V) ± *U*(V)	Luminous Flux *Φ* (lm) ± *U*(lm)	Correlated Color Temperature *T* (K) ± *U*(K)
352	1.90000 ± 0.00023	86.5070 ± 0.0030	1913 ± 33	2753 ± 25
			1909 ± 33	2752 ± 25
			1910 ± 33	2752 ± 25
		average	**1911 ± 33**	**2752 ± 25**
353	1.90000 ± 0.00022	86.0681 ± 0.0031	1846 ± 32	2730 ± 25
			1843 ± 32	2730 ± 25
			1847 ± 32	2730 ± 25
		average	**1845 ± 32**	**2730 ± 25**
355	1.90000 ± 0.00023	87.7782 ± 0.0032	1879 ± 33	2745 ± 25
			1873 ± 33	2745 ± 25
			1880 ± 33	2745 ± 25
		average	**1877 ± 33**	**2745 ± 25**